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The Amazing World of Nanotechnology

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Abstract

Nanotechnology has become the buzzword of present day society. We find some news item flashing in the media every other day. Expectations and curiosity of the commoners have naturally been elevated to unexpected levels. This article gives an overview of the science and technology of the nano-world. Starting from a historical perspective, it is aimed to describe the development of this exciting ***new****(!) branch of science and technology as it stands today and what to expect in the future. Please note the exclamation mark (!) I have put beside the word new in the previous sentence. I shall leave to the judgment of the reader, whether the use of the adjective is appropriate in this context.*

The word *nano* is derived from the Greek word '*nanos*' meaning '*dwarf*'. Mathematically, the prefix nano is used to describe 1 part in a billion of something. Thus 1 nanometer is one billionth of a meter or 10^{-9} meter. A few examples will give an idea about what does such a dimension mean:

1. Consider a straight line 1 inch in length. If you break it up in small parts each one a nanometer (abbreviated as 'nm') in length, you will get over 25 million such parts.

2. Take a slice of the human hair across its diameter. If you put the 1 nm pieces of the above example side-by-side along the cross-section of the hair, you will need about 50 thousand such pieces to cover the entire width.

If you have already started feeling dizzy with those numbers, let me remind you that our world is made up of elements much smaller than a nanometer in dimension. Think of the Hydrogen atom, two of which we gobble up every time we drink a molecule of water. If you could isolate hydrogen atoms and put a number of them shoulder to shoulder along a line, it will take nearly ten (10) hydrogen atoms to fill up one nanometer of length; the tiniest distance you perhaps thought conceivable while working out the first example above. Imagine how many hydrogen molecules you swallow every time you drink a glass of water.

The numbers are no doubt overwhelming. But why are we so interested in them? The reason is, when known materials are reduced in size to such dimensions, their properties significantly change from those in bulk quantities, eg., gold changes colour to blue, red and orange as we decrease the size of the particles. Strength of materials has been found to increase many fold at such dimensions, which is utilized to synthesize new light-weight strong materials replacing metals for many applications. Corrosion resistant paints and coatings are also developed using nano particles as an integral component. As the particle size decreases their surface area to volume increases making them more reactive in many cases. This phenomenon led to the development of new generation of catalysts that can break down oil and grease molecules, such as those employed in self-cleaning coatings on glass and other surfaces. In the field of electronics, computers and communication, new generation electronic and photonic devices have emerged paving the way for high speed machines consuming lower power. High efficiency lighting and solar cells are expected to bring in a new revolution in power systems that may ultimately be a viable and safer alternative to fossil fuels than nuclear energy. In the field of medicine, new diagnostic tools and drug delivery mechanisms are being developed. In the First Nanotechnology Conclave organized by the Confederation of Indian Industries in February 2006, the then President of India, Dr. A.P.J. Abdul Kalam summarized the prospects of the field as "... *The next ten years, will see nanotechnology playing a dominant global business role, with the technology expected to go beyond estimates and cross the figure of one trillion ...*". The global business volume in nanotechnology is expected to reach anywhere between half to two trillion US Dollars by the year 2015.

So, what is nanotechnology? The nano-domain is loosely defined to encompass materials and systems having dimensions in the range of 1 to 100 nanometers. As we have discussed earlier, systems at these dimensions are composed of a few to a few tens of atoms or molecules. Considering this, we may say that **Nanotechnology** *deals with design, characterization and application of structures produced by manipulation of materials at atomic and molecular levels.* **Nanoscience** on the other hand is *the study of phenomena and characteristics of materials at atomic, molecular and macromolecular scales, the properties which differ significantly from those at a larger scale.*

Human inquisitiveness always generated fascination towards observing tiny objects. The journey began with the invention of an optical magnifying instrument in the late sixteenth century by two Dutch spectacle makers, Zaccharias Janssen and his son Hans, while experimenting with several lenses in a tube. The results of these experiments led to the invention of the telescope by Galileo in the seventeenth century and the microscope by Anton van Leeuwenhoek of Holland who used it to study bacteria and other living and non-living objects. The microscope was further improved upon in the following centuries and reached a level of perfection by the mid-nineteenth century. Recent developments in optical microscope design resulted in improving the contrast between the object under observation and its background through better illumination using polarized light, digital photography and image processing software. Looking into even smaller objects by increasing the magnifying power is not possible as the resolving power of the optical microscope, even with perfect lenses is limited to half the wavelength of the light. Considering an average wavelength of white light to be 555 nm, the resolution was limited to 275 nm. This means that two objects closer to each other by less than 275 nm would appear as one object. These dimensions are far too large when compared to molecular dimensions. We need shorter wavelengths to look at smaller objects.

The twentieth century started with Max Plank's revolutionary proposition of the quantum theory[1]. The exemplary experiments and ideas that followed in the following thirty years[2] changed the way scientists think about physics. The French physicist Louis de Broglie's hypothesis of matter waves, that a particle moving at high speed have wave like properties, proposed in 1925 and subsequently verified through experiments by others, led to the invention of the electron microscope in 1931 by the German scientists Max Knoll and Ernst Ruska. In this instrument, electrons are accelerated by an electric field strong enough so that their wavelength become orders of magnitude smaller than that of white light thus paving the way to look into molecular dimensions. The following years saw many new discoveries using this new scientific toy. Electron microscopes, however, remained as a diagnostic tool mostly for observing tiny objects in their various manifestations. These observations led us into exploring the nano-world as it is perceived today. A significant discovery of such observations is the mystery of the King Lycurgus Cup, a dichroic glass cup dating back to 4th Century AD Roman era. It looks like an opaque green cup in reflected light, but observed in transmitted light its appearance changes to a glowing translucent red[3]. Recent observation through a high power transmission electron microscope revealed that the glass contains tiny colloidal gold and silver particles which give rise to this unusual property. So, nanotechnology was practised even in the Roman era. But did they really know the science behind it? We will never know. In the Indian context, *Kajal* or *Surma* has been in use as a cosmetic of the eye since some unrecorded past, with the belief that it also has some therapeutic values. Modern studies show that the product contains ample amount of carbon nano-particles. In Ayurvedic medicine preparation we find references to processes known as *bhasma* and *churna*[4]. *Bhasma* is a process of generating fine powders by calcination of a substance in a closed pit, usually fired by burning cow-dung cakes while *churna* refers to mixing together of different powders in prescribed proportions.

People obviously knew methods of preparing nano-particles and put them into practical use for thousands of years. The applications, however, were limited to preparing the particles by some means and use them as an ensemble distributed evenly in a larger body. The idea of arranging arrays of particles of molecular dimensions in a pre-organized manner was first proposed by Richard Feynman in a historical lecture[5] entitled "There's Plenty of Room at the Bottom", in the annual meeting of the American Physical Society at the California Institute of Technology on December 29, 1959. He conceived the idea that the lens system of the electron microscope could also be used to focus the electron wave to a tiny region and impart enough energy so as to engrave any pattern on a surface, like we focus the Sun rays using a magnifying glass to burn a hole in a piece of paper. Many years later, this idea manifested in the Electron Beam Lithography system, that is now central to the manufacturing of modern VLSI chips. Feynman also mentioned in his lecture that like manipulating electron beams, a stream of ions can also be focused anywhere, albeit at a low enough energy, so that the molecules get deposited on the surface. This technique known today as Focussed Ion Beam Lithography is used in laboratories for the fabrication of nano-structures used in novel materials and devices. Extend your imagination a little further and think of "*arranging the atoms one by one the way we want them*" as Feynman proclaimed and synthesize new compounds that are yet to see the light of the earth. A fascinating new era will begin when scientists will be able to cook up compounds having the desired properties by combining the natural elements, like an expert chef prepares a recipe to a given taste from the ingredients in his kitchen.

References:

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